Technologies for Turbofan Noise Reduction

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ABSTRACT

An overview presentation of NASA's engine noise research since 1992 is given for subsonic commercial aircraft applications. Highlights are included from the Advanced Subsonic Technology (AST) Noise Reduction Program and the Quiet Aircraft Technology (QAT) project with emphasis on engine source noise reduction. Noise reduction goals for 10 EPNdB by 2007 and 20 EPNdB by 2022 are reviewed. Fan and jet noise technologies are highlighted from the AST program including higher bypass ratio propulsion, scarf inlets, forward-swept fans, swept/leaned stators, chevron nozzles, noise prediction methods, and active noise control for fans. Source diagnostic tests for fans and jets that have been completed over the past few years are presented showing how new flow measurement methods such as Particle Image Velocimetry (PIV) have played a key role in understanding turbulence, the noise generation process, and how to improve noise prediction methods. Tests focused on source decomposition have helped identify which engine components need further noise reduction. The role of Computational AeroAcoustics (CAA) for fan noise prediction is presented. Advanced noise reduction methods such as Herschel-Quincke tubes and trailing edge blowing for fan noise that are currently being pursued in the QAT program are also presented. Highlights are shown from engine validation and flight demonstrations that were done in the late 1990's with Pratt & Whitney on their PW4098 engine and Honeywell on their TFE-731-60 engine. Finally, future propulsion configurations currently being studied that show promise towards meeting NASA's long term goal of 20 dB noise reduction are shown including a Dual Fan Engine concept on a Blended Wing Body aircraft.

Technologies for Turbofan Noise Reduction

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Manchester, United Kingdom
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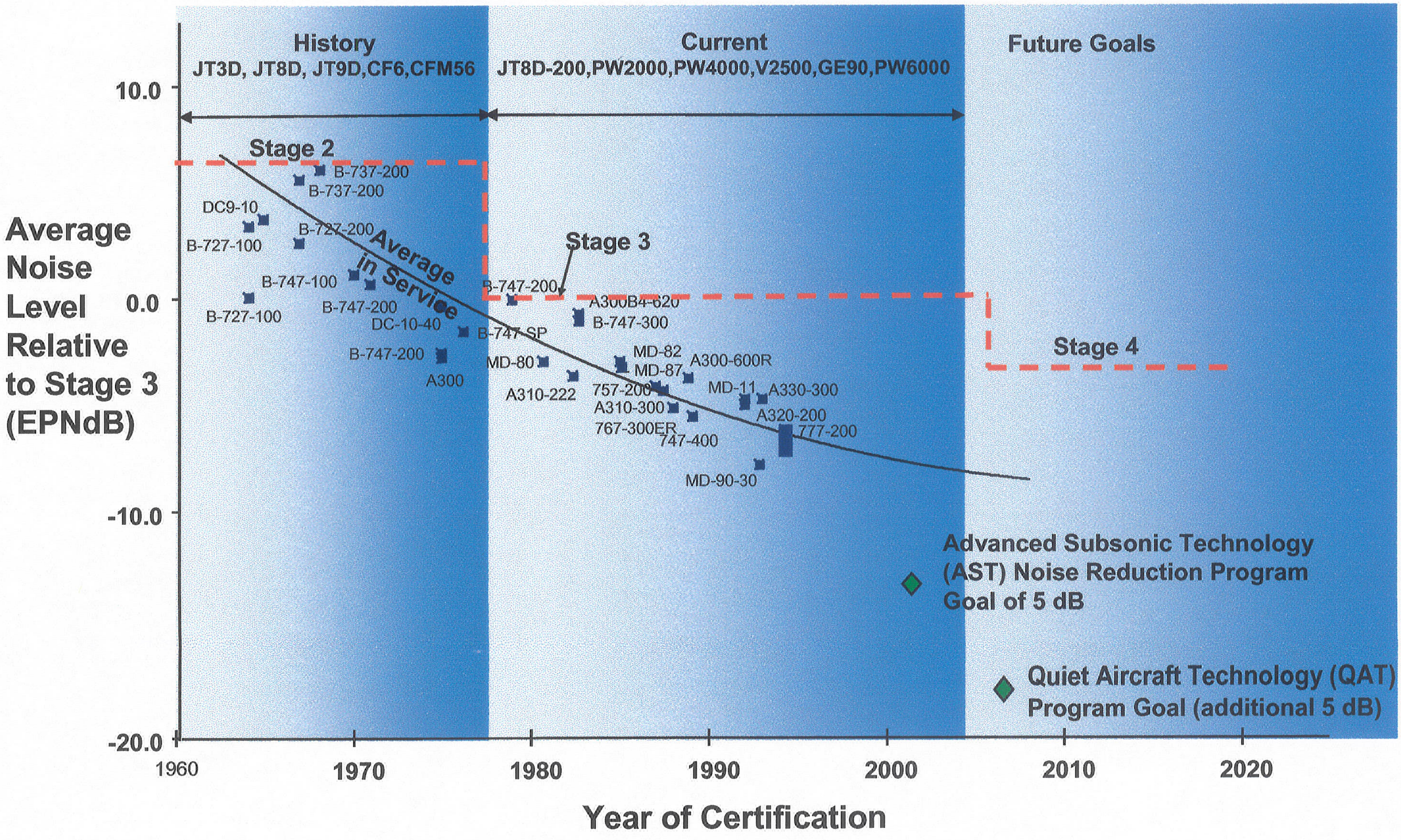
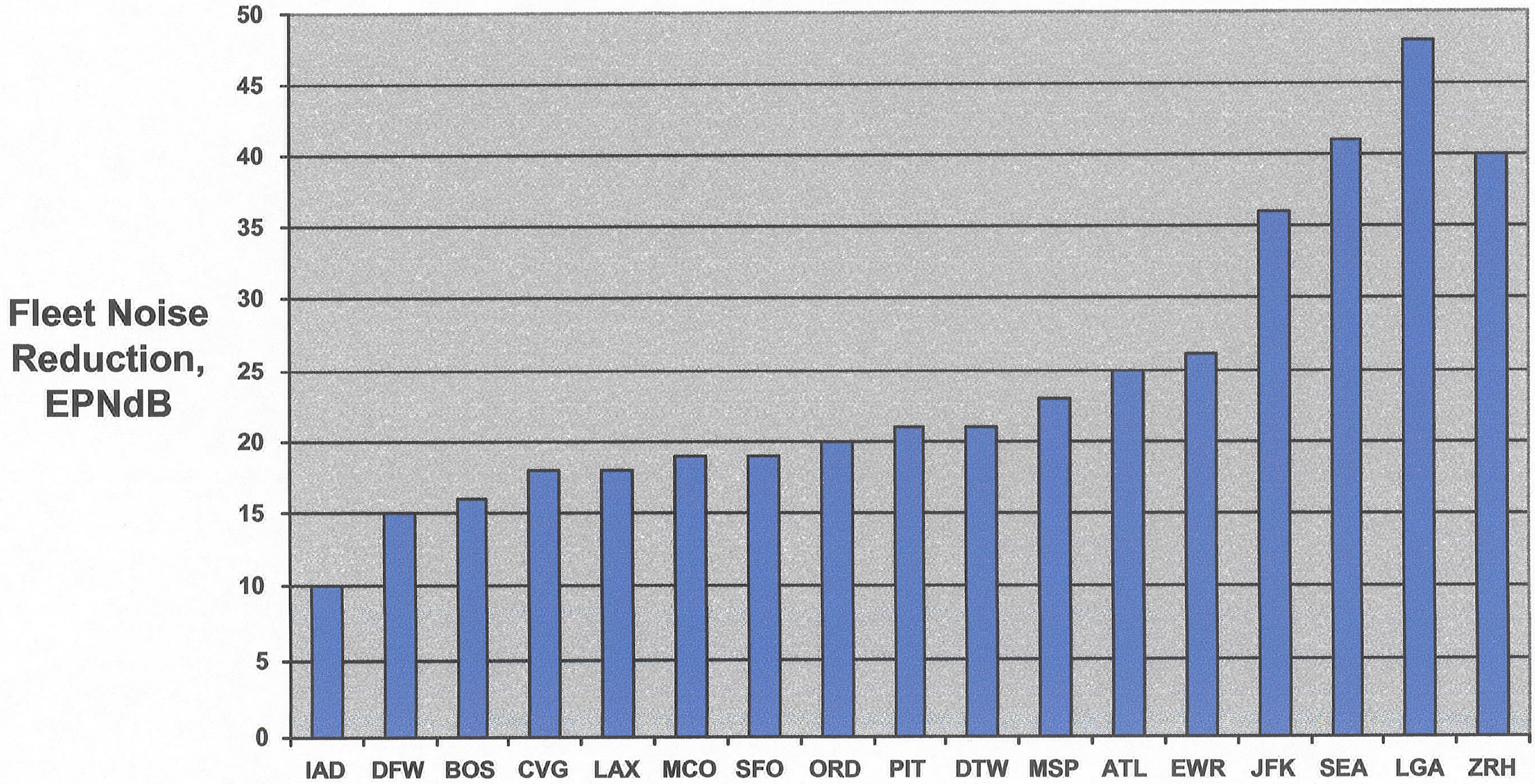
New Technology Enables Aircraft To Meet Future Requirements



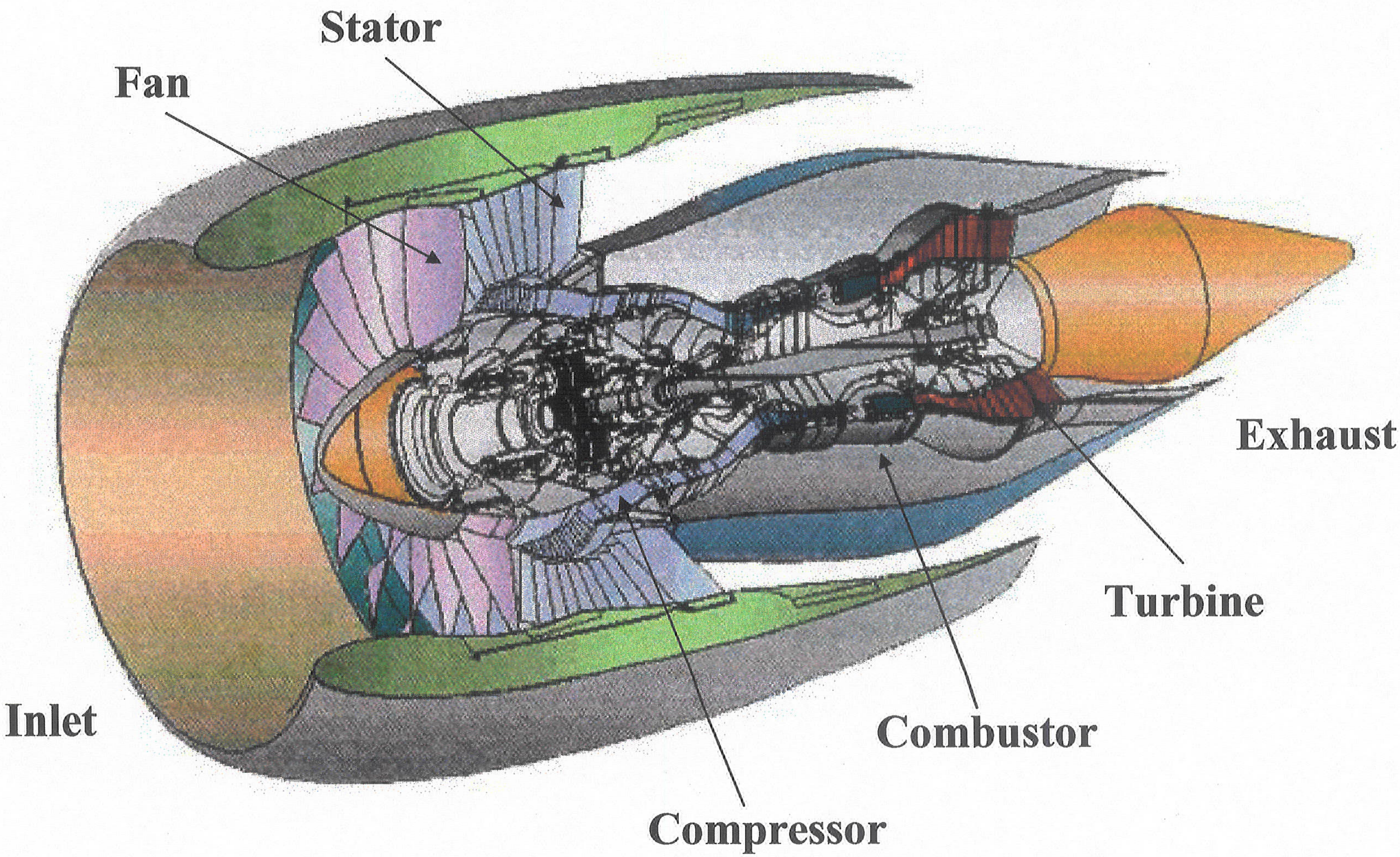
Aircraft Fleet Noise Reduction Needed For 55 LDN Noise Contours Within Airport Boundaries

According to a document from the U.S. Environmental Protection Agency (EPA) published in the 1970's, 55 LDN is the outdoor noise exposure level "requisite to protect the public health and welfare with an adequate margin of safety". The phrase "health and welfare" is defined as "complete physical, mental and social well-being and not merely the absence of disease and infirmity".



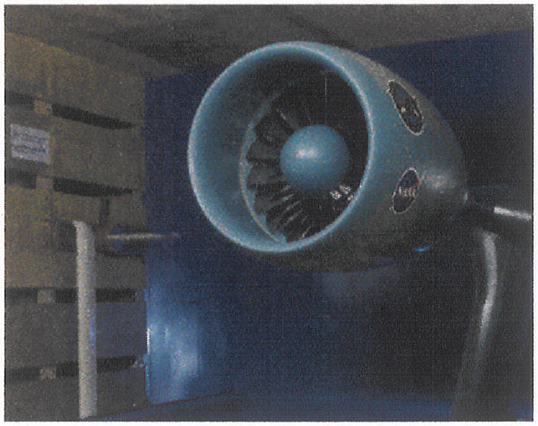
Analysis by Don Garber, NASA Langley, using NoiseMap

Pratt & Whitney's PW8000 Turbofan Engine (Conceptual)



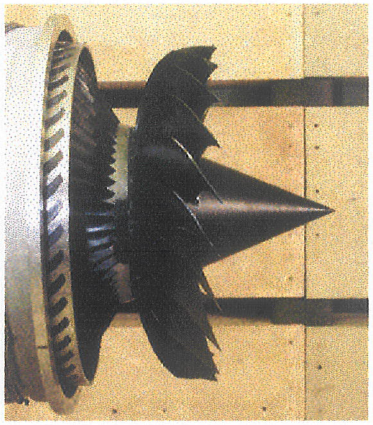
Engine Noise Reduction Technologies

Higher Bypass Ratio

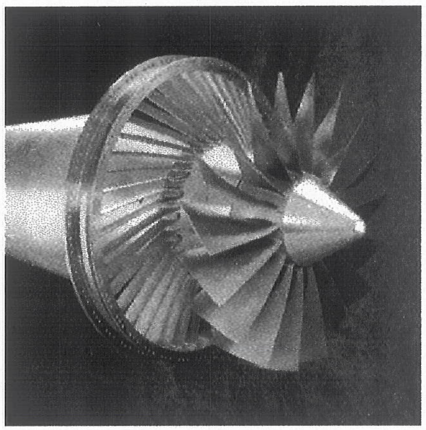


Scarf Inlets

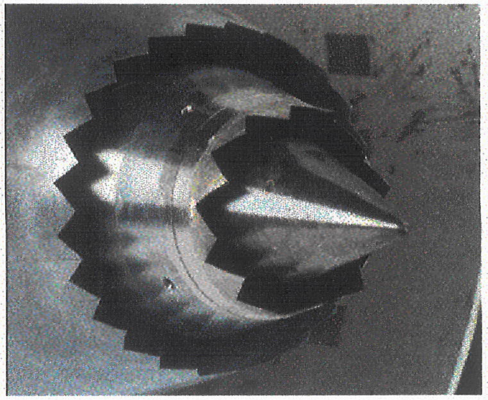
Forward-Swept Fans



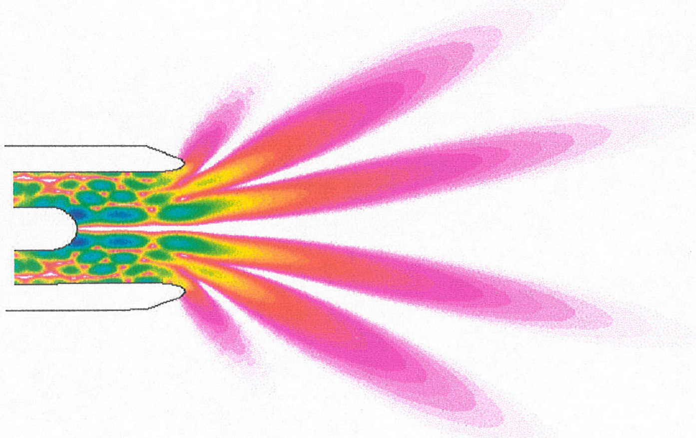
Swept/Leaned Stators



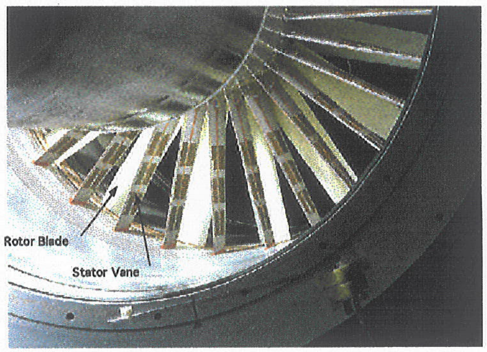
Chevron Nozzles



Noise Prediction



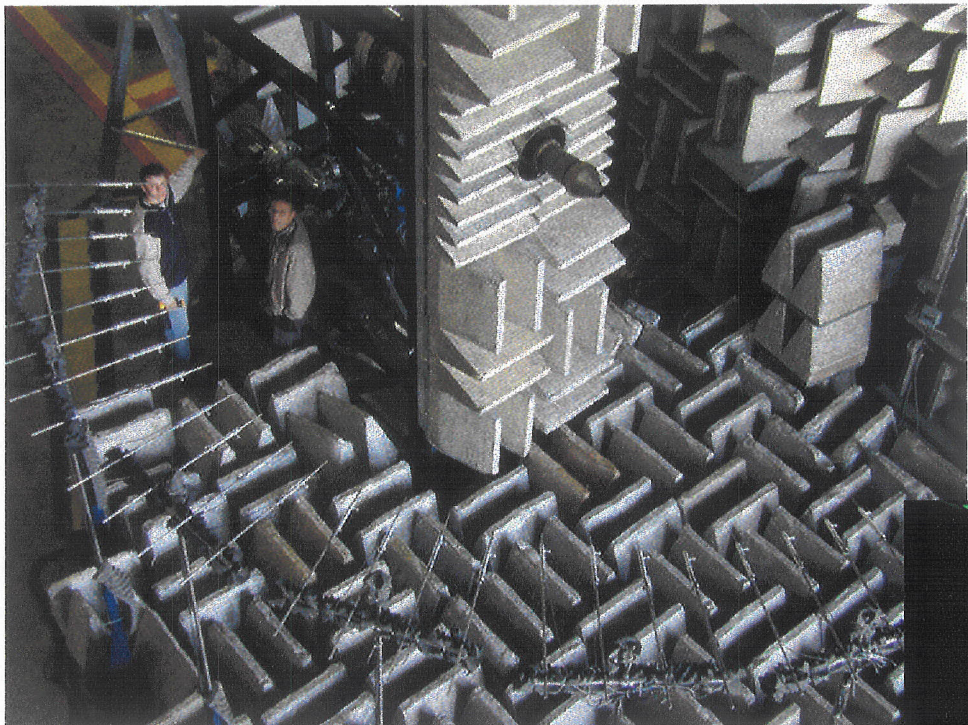
Active Noise Control



OUTLINE

- Source Diagnostics Tests
- Fan Noise
- Jet Noise
- Static Engine Tests & Flight Validation
- Future Directions

Small Hot Jet Acoustic Rig (SHJAR)

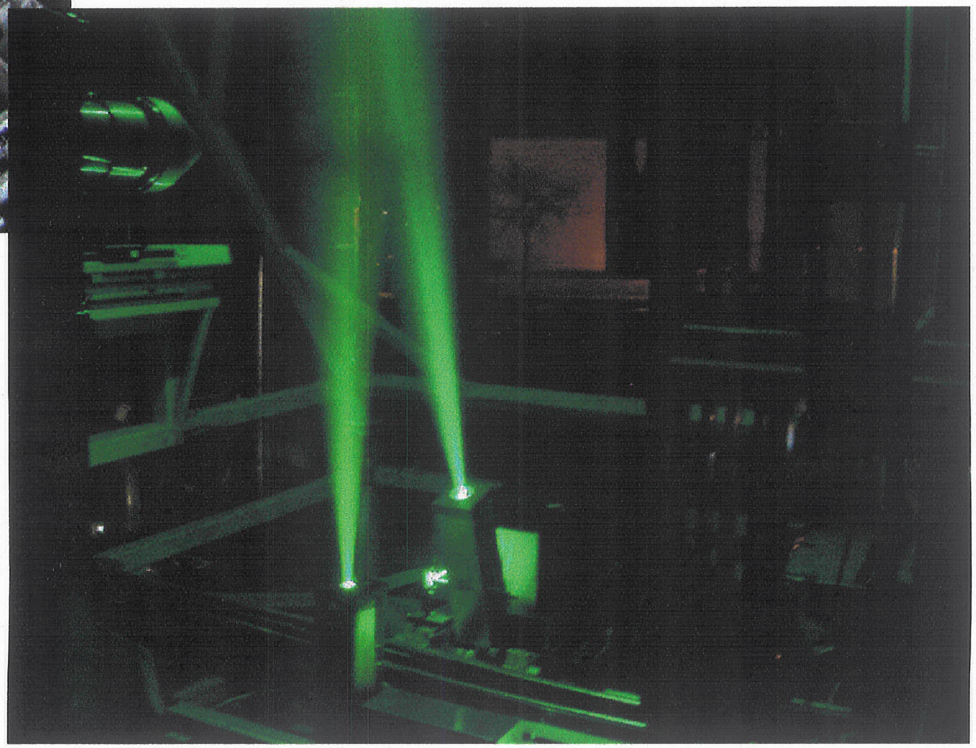


Far-field Acoustics

Koch, Bridges, Brown & Khavaran
(INCE NOISE-CON 2003)

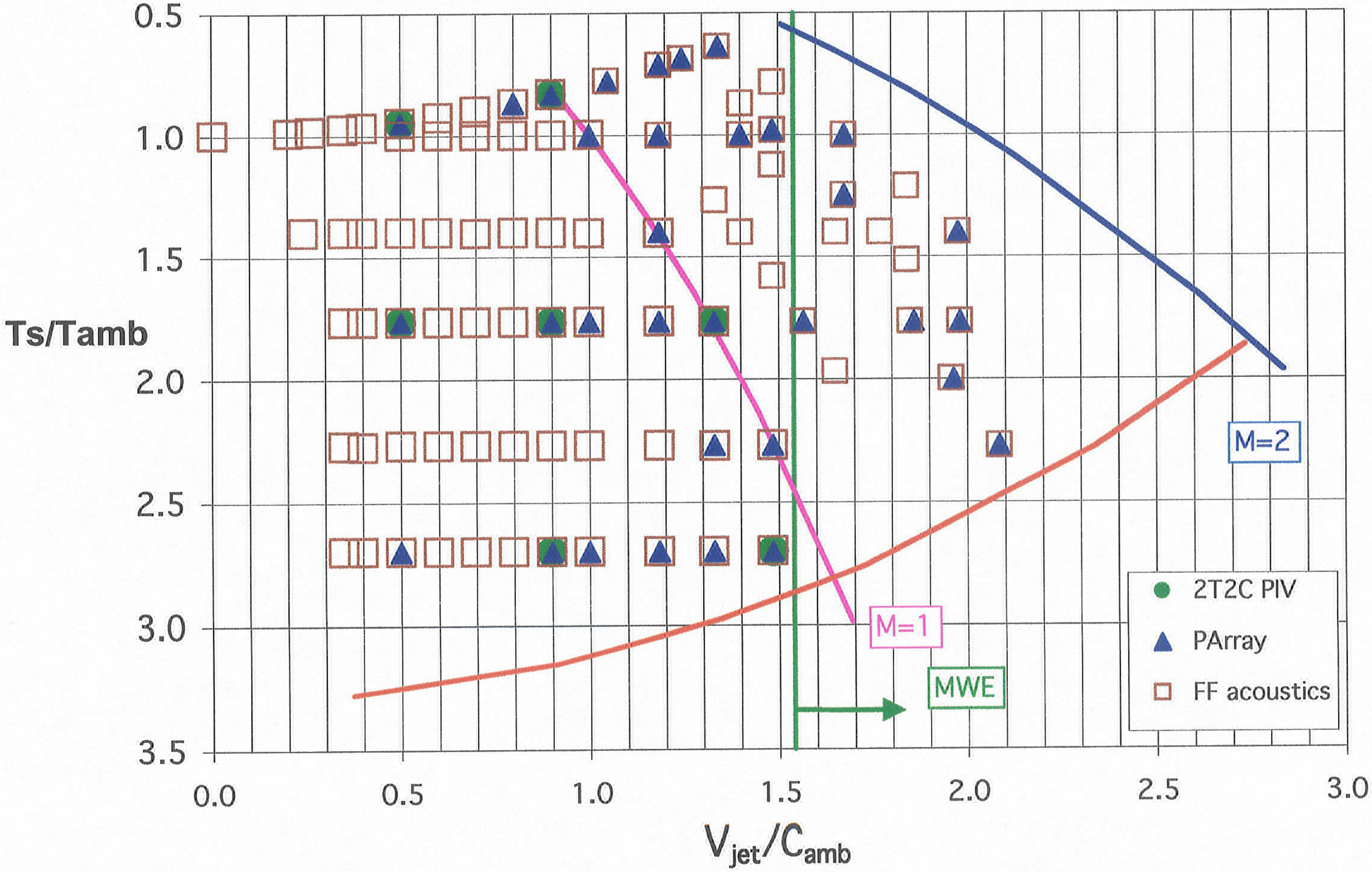
Bridges & Wernet (AIAA Paper 2003-3130)

Flow Diagnostics



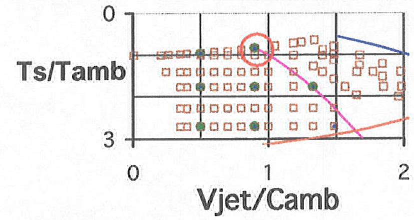
Jet Noise Baseline Data For CFD/CAA Validation

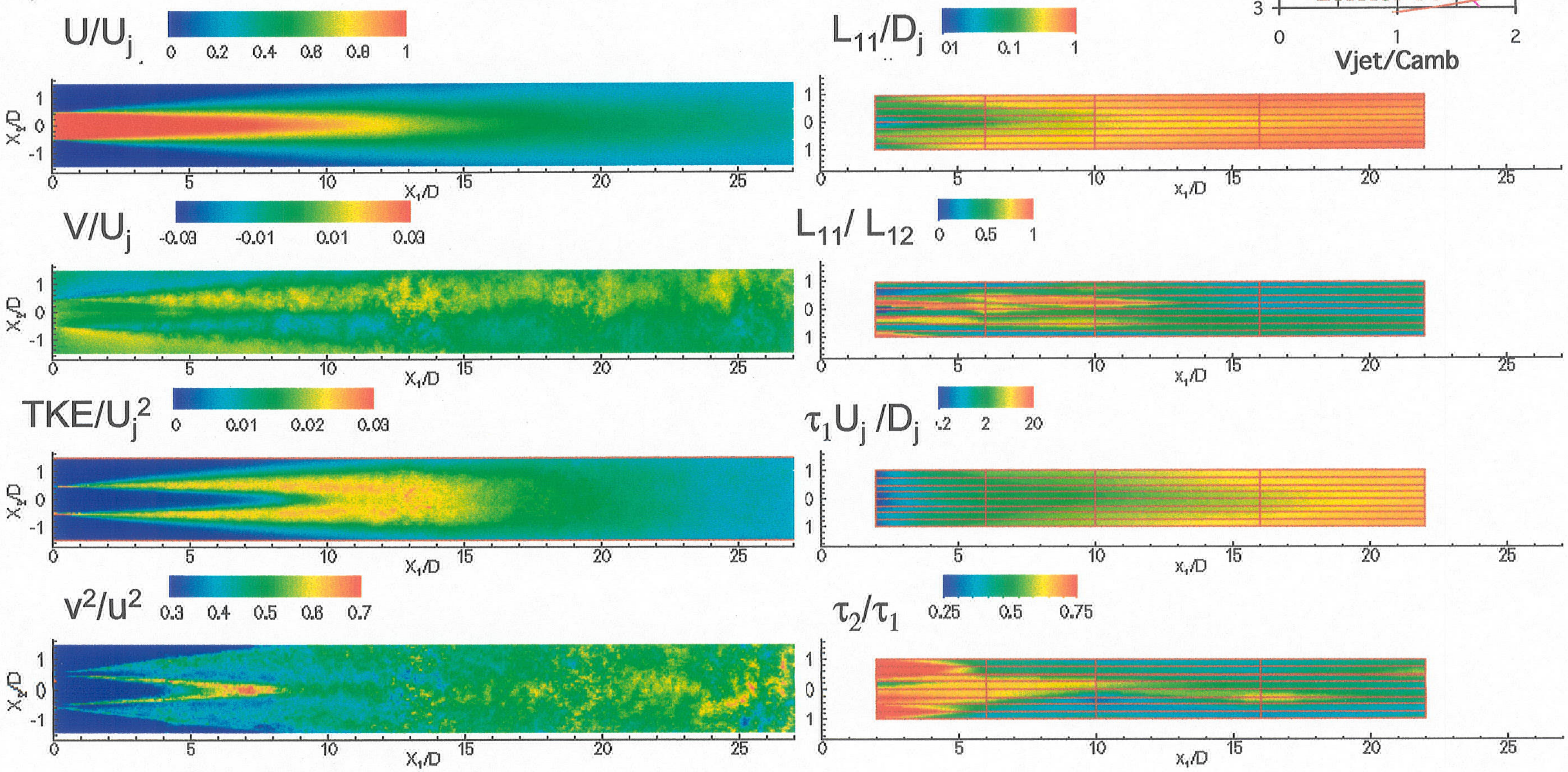
- Provide reliable data base for experimental and analytical comparisons
- Cover wide range of subsonic and supersonic conditions (Tanna data)



Jet Noise Baseline Data For CFD/CAA Validation

- **Objective: Turbulent flow statistics**



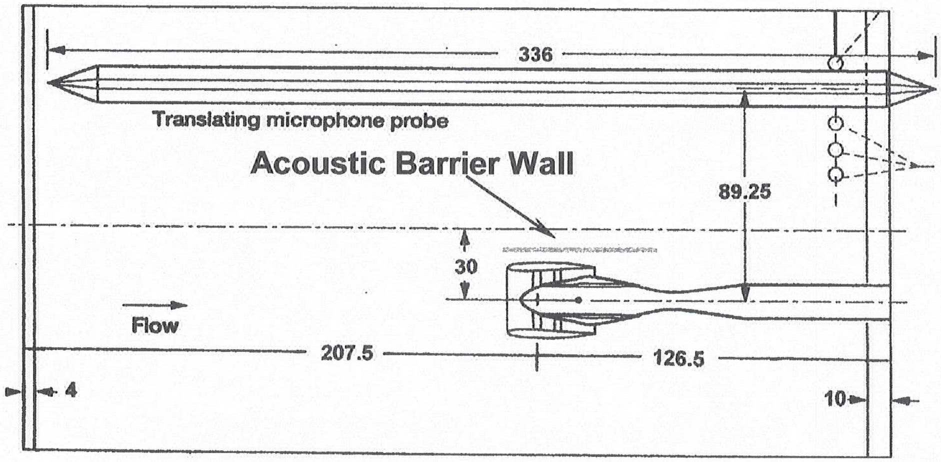


Bridges & Wernet (AIAA Paper 2002-2484)

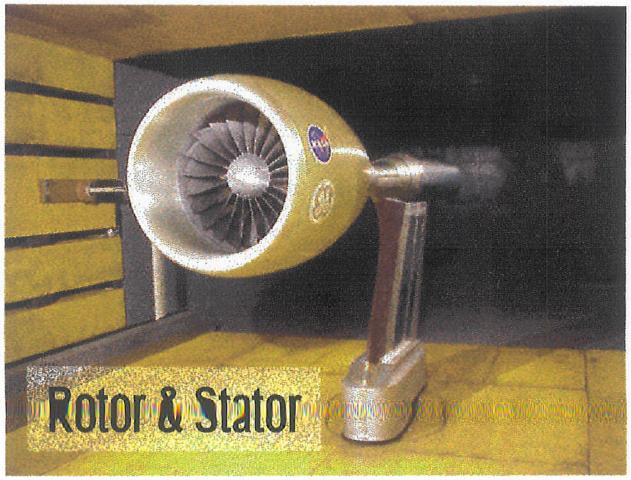
Fan Source Diagnostics Test (SDT)

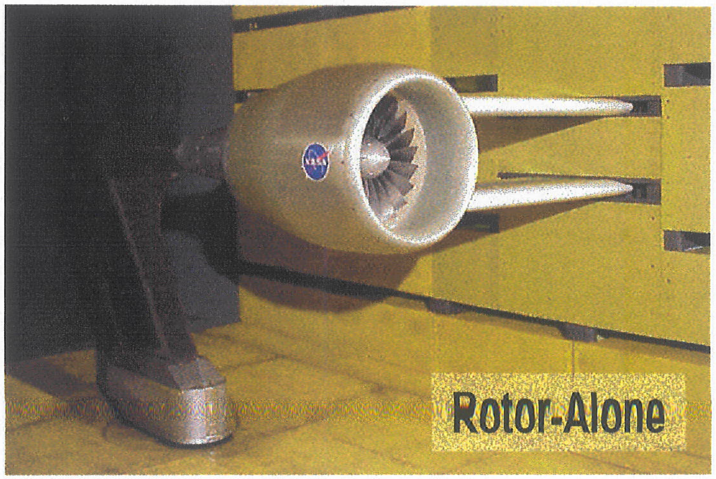
☐ Approach

- Comprehensive Aero-Acoustic Testing
- Advanced Diagnostics
- Source Separation
  - Inlet vs. exhaust
  - stage vs. rotor-alone

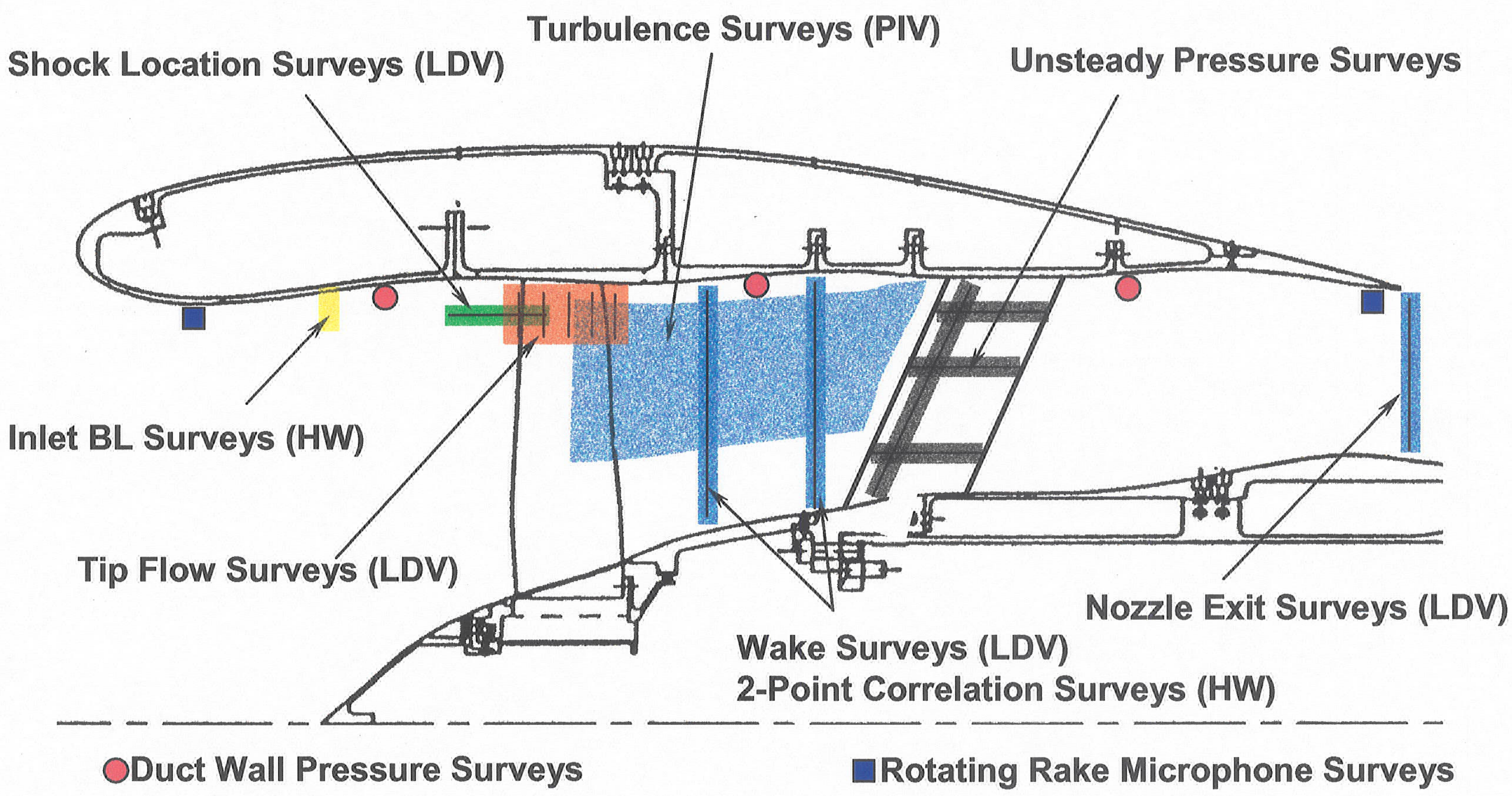


Top View Schematic of NASA's 9' x 15' Low-Speed Wind Tunnel





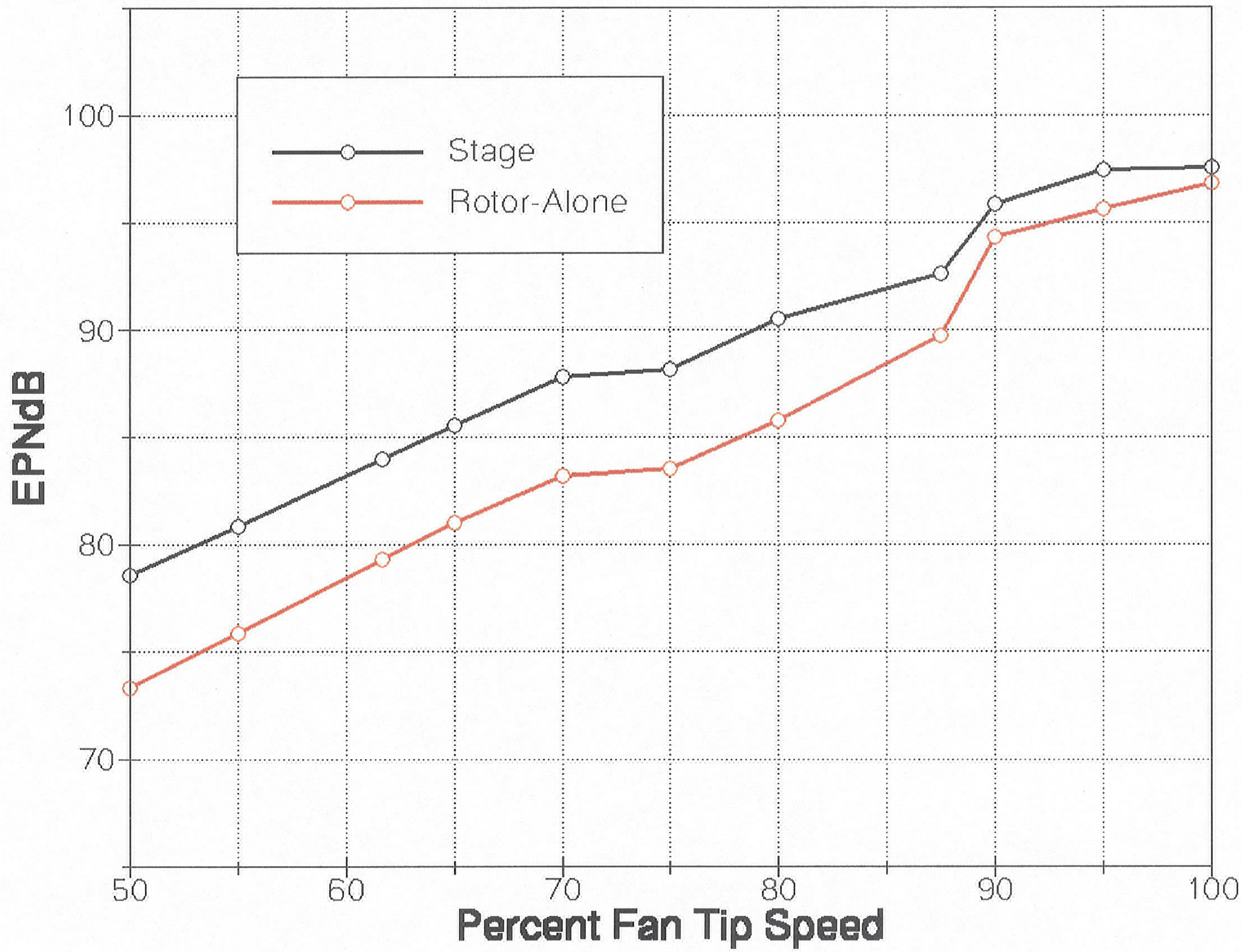
Fan Source Diagnostics Test Summary



Traversing Microphone Farfield Surveys

Tested 2 Fans, 3 Outlet Guide Vanes and Rotor-Alone Configurations at Multiple Fan Tip Speeds

Rotor-Alone Fan Noise



Fan Source Diagnostics Test - References

Rotor Alone Aerodynamic Performance Results *Hughes et. al (AIAA Paper 2002-2426)*
Farfield Acoustic Results *Woodward et. al (AIAA Paper 2002-2427)*
Tone Modal Structure Results *Heidelberg (AIAA Paper 2002-2428)*
Wall Measured Circumferential Array Mode Results *Premo & Joppa (AIAA Paper 2002-2429)*
Vane Unsteady Pressure Results *Envia (AIAA Paper 2002-2430)*
LDV Measured Flow Field Results *Podboy et. al (AIAA Paper 2002-2431)*
Computation of Rotor Wake Turbulence Noise *Nallasamy et. al (AIAA Paper 2002-2489)*

Fan Tone Noise Prediction (Frequency Domain)

❑ Methodology

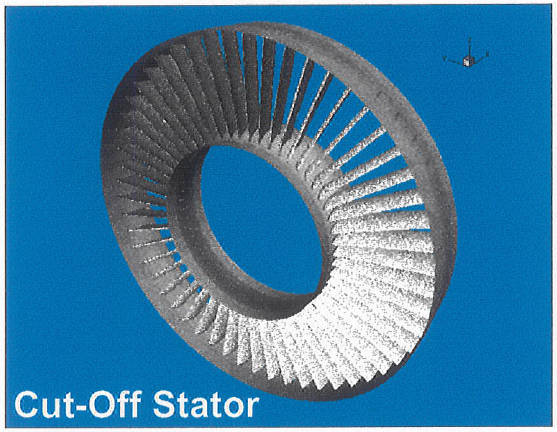
- Fan Wake Description: Steady RANS
- OGV Acoustic Response: Linearized Euler

Verdon et al. (NASA/CR-2001-210713)

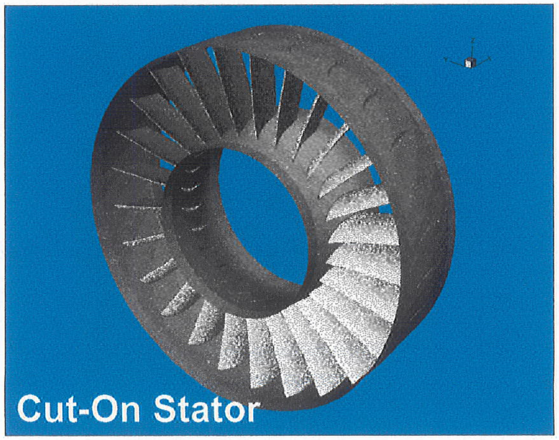
Exhaust Tone Levels: Prediction Data*

Cut-Off Stator (2xBPF)			Cut-On Stator (1xBPF)		
Mode: (m,n)	Power (dB)		Mode: (m,n)	Power (dB)	
(-10,0)	113	111	(-4,0)	124	124
(-10,1)	100	97	(-4,1)	120	120
(-10,2)	101	103			
(-10,3)	102	98			
Total	114	112	Total	125	125

* Data includes a recently discovered 3 dB correction



Cut-Off Stator



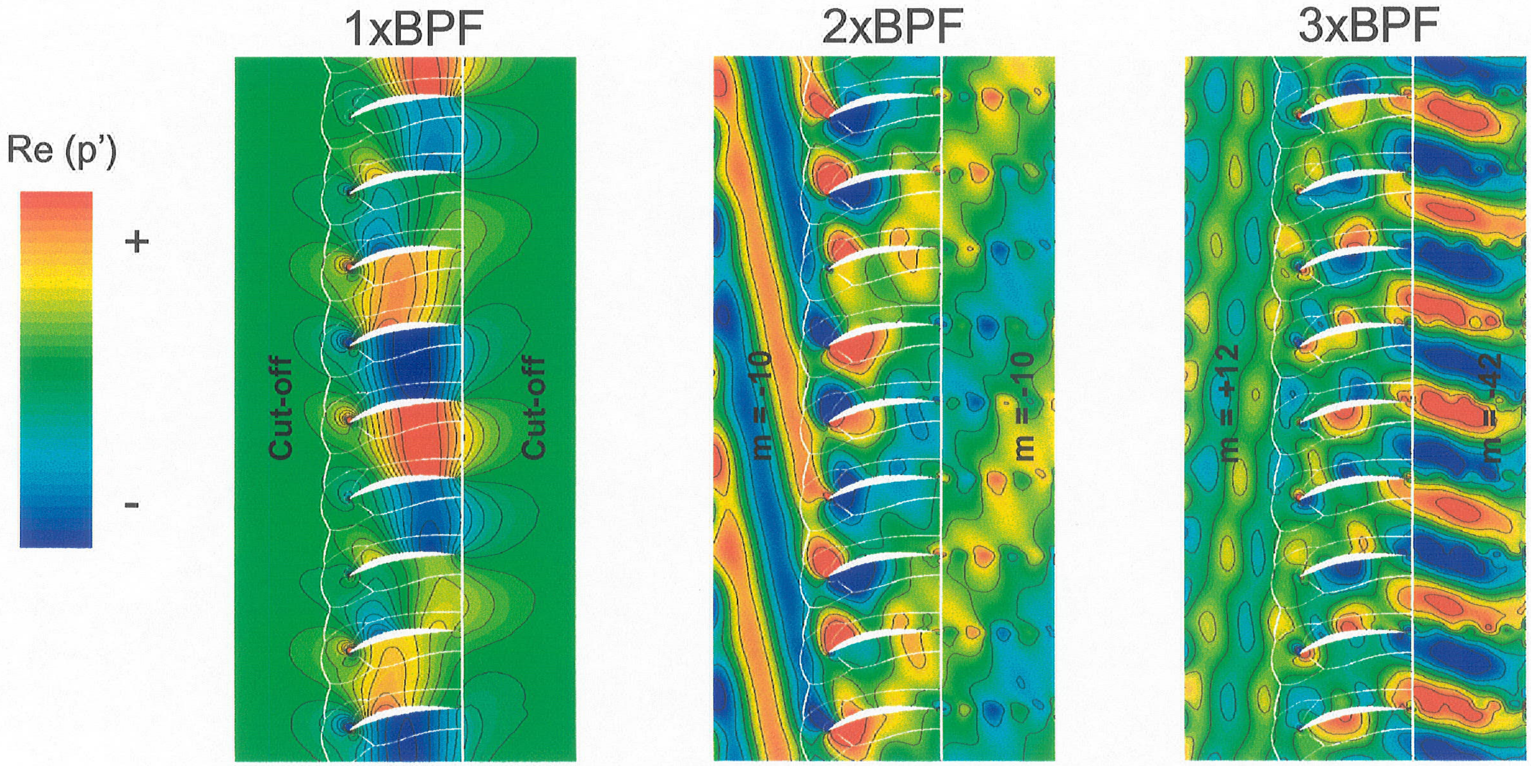
Cut-On Stator

Computational Aeroacoustics for Fan Noise Prediction (Time-Domain)

❑ Methodology

Nallasamy et al. (AIAA Paper 2003-3134)

- Time-Accurate, Non-linear & Inviscid Simulation
- Validated in 2D. Extension to 3D is Underway



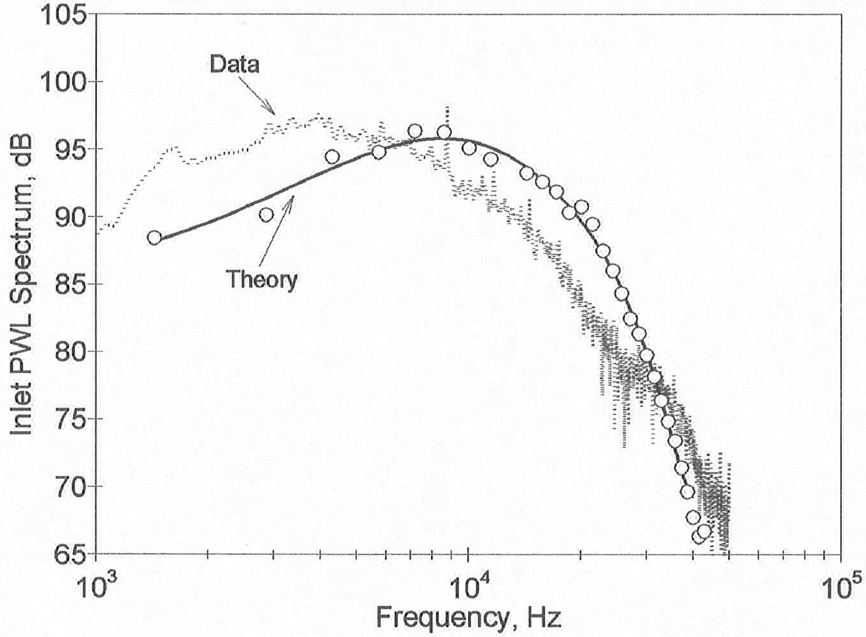
Harmonic content of unsteady pressure (only 9 passages shown)

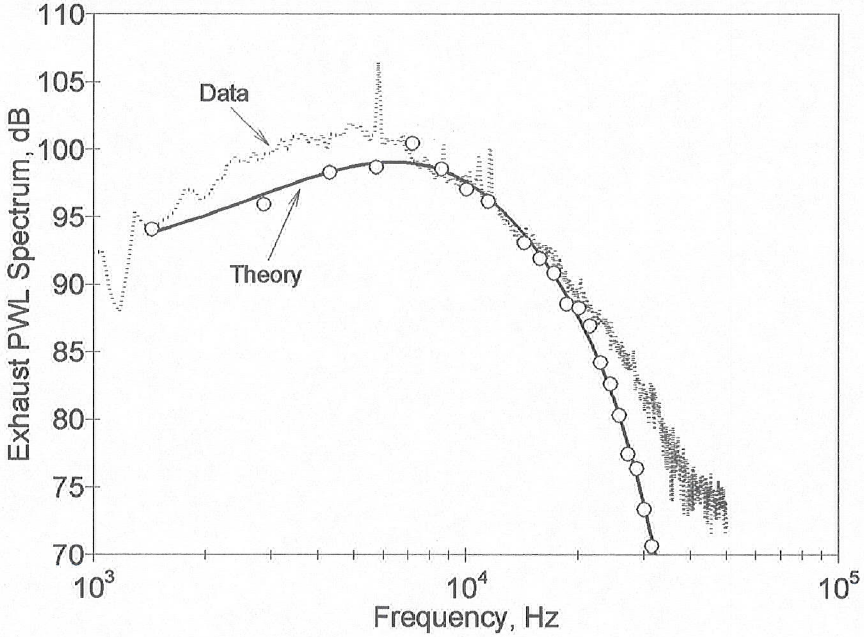
Fan Broadband Noise Prediction

Nallasamy et al. (AIAA Paper 2002-2489)

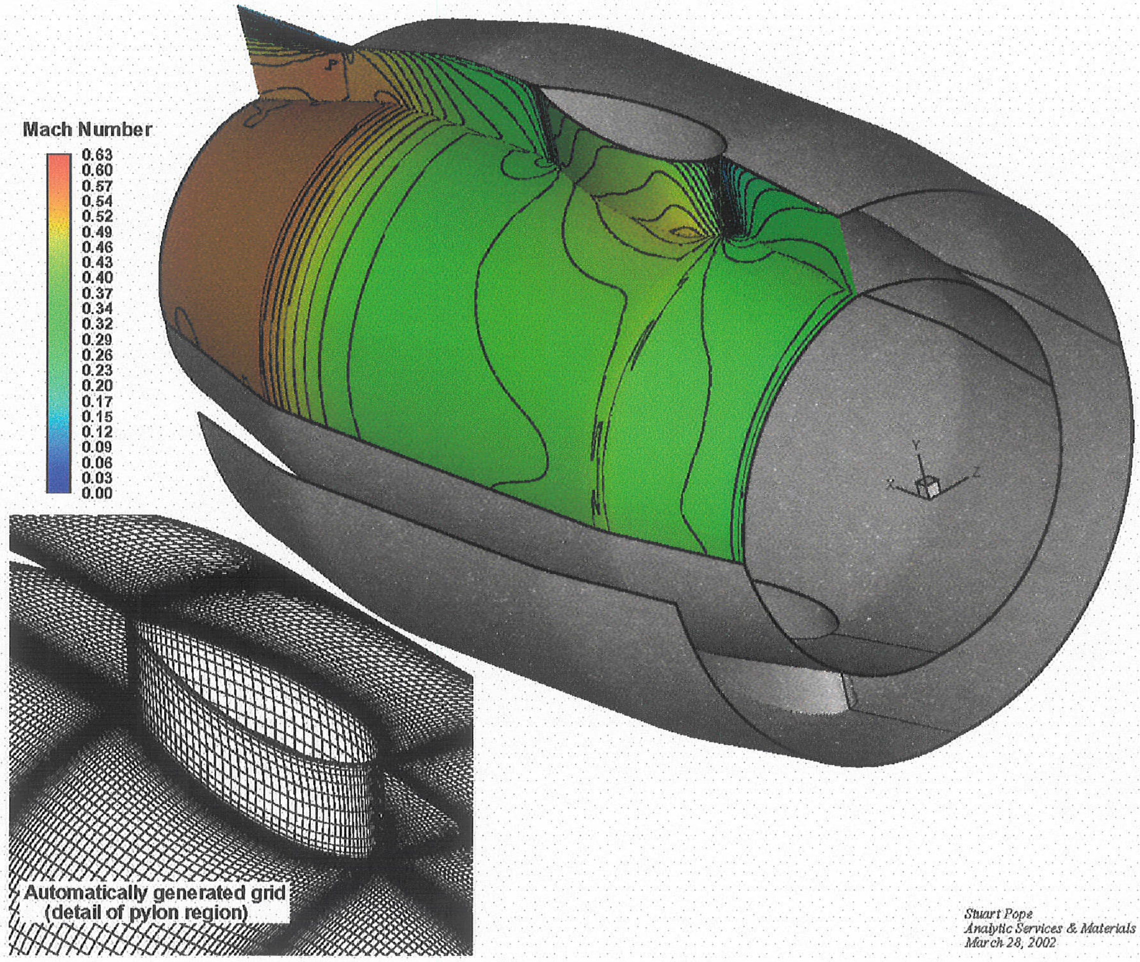
- Methodology
  - ➢ **Fan Wake Turbulence Description: Steady RANS**
  - ➢ **OGV Acoustic Response: Strip-wise lift response (2D cascade)**
    Classical duct acoustics (3D)

Inlet and Exhaust PWL at Approach Condition (Stator Contribution Only)
Data includes both coherent and broadband, theory only includes broadband

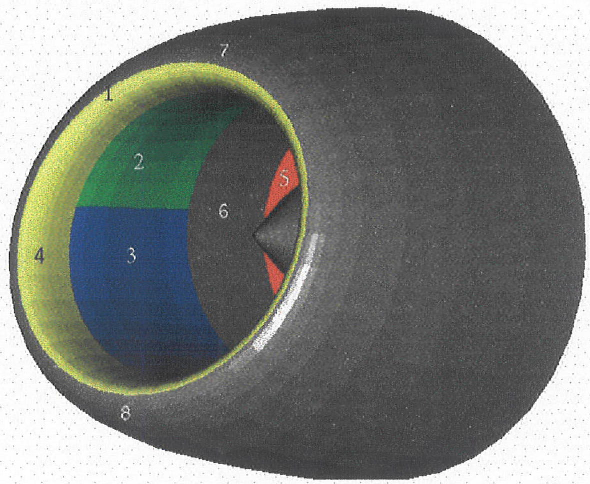




Fan Noise Duct Propagation
CDUCT-LaRC Code



- ✓ Accounts for realistic geometries
- ✓ Uses CFD to achieve higher quality acoustic predictions
- ✓ Couples with source codes like LINFLUX or TFaNS

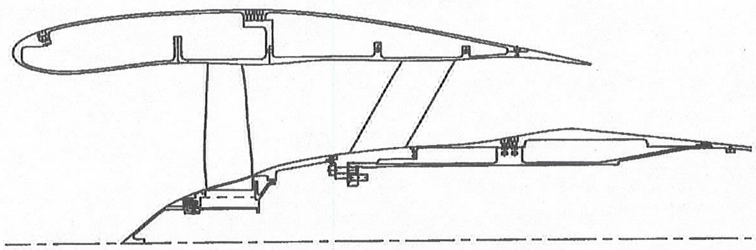


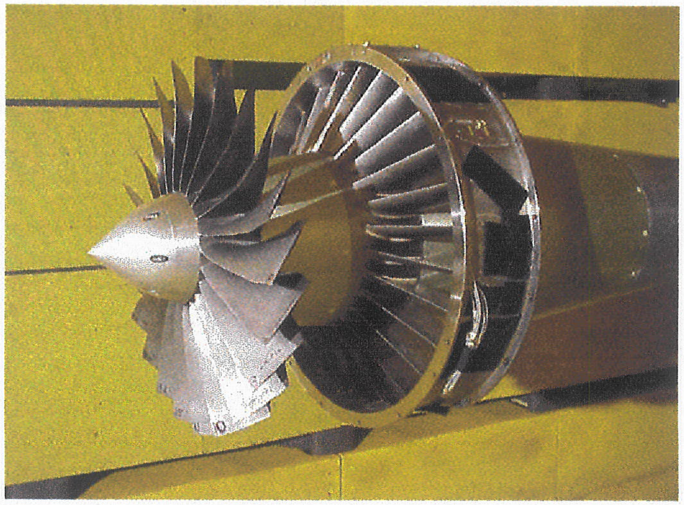
Scarf Inlets

Fan Noise Reduction

❑ Low-Count Swept OGV

- ➢ Low Count Reduces Broadband Noise
- ➢ Sweep Minimizes BPF Tone Penalty

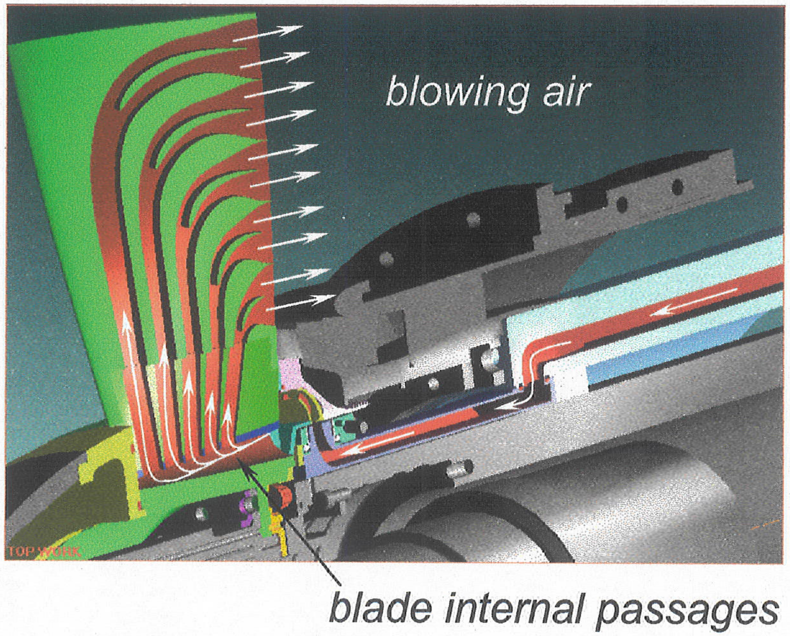




Woodward et al. (AIAA Paper 2002-2427)

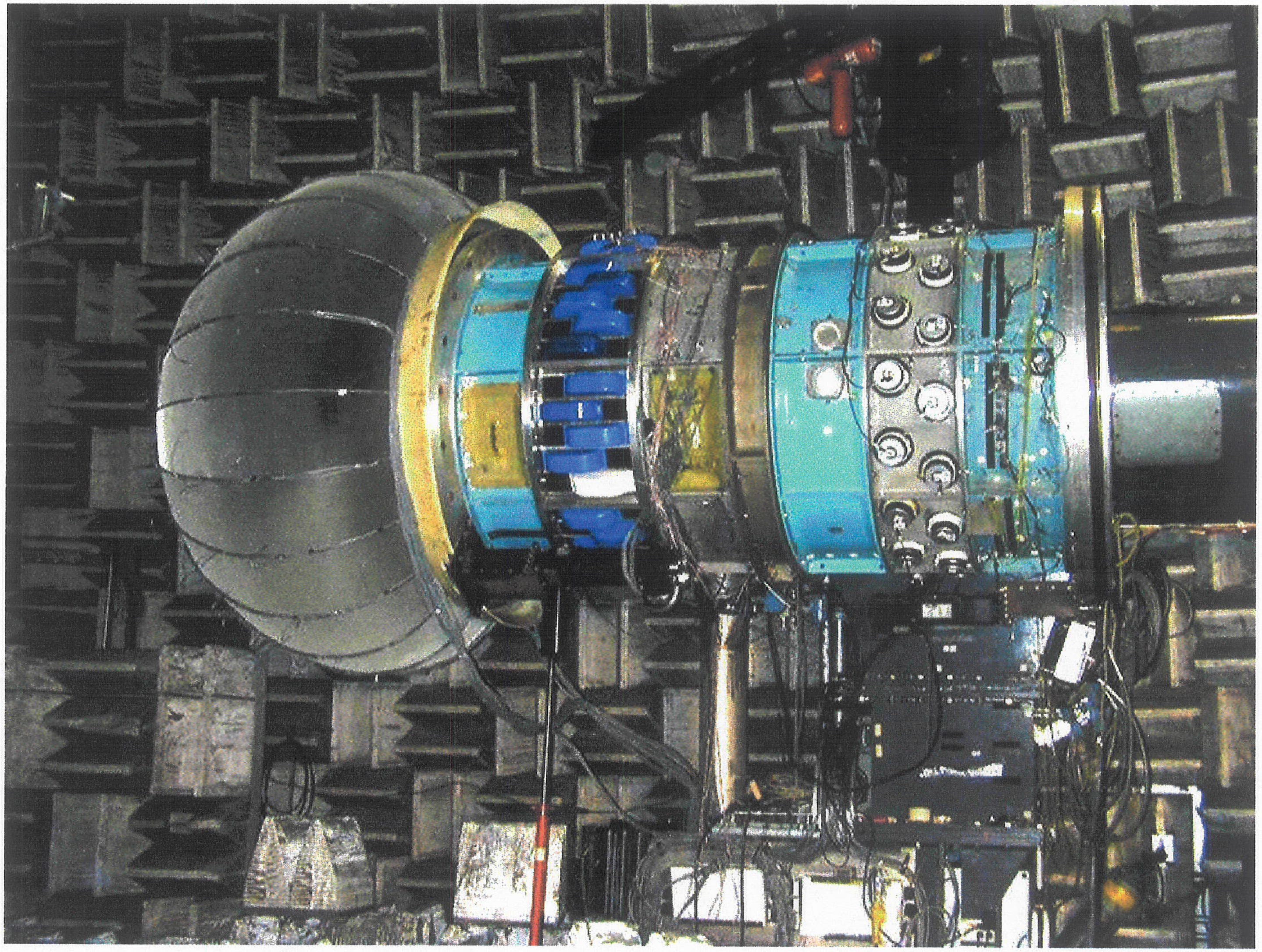
❑ Trailing Edge Blowing

- ➢ Fill-In the Rotor Wake
  - ➢ reduces tone noise
  - ➢ reduces broadband noise



Sutliff et al. (International J. of Aeroacoustics, Vol. 1, No. 3, 2002)

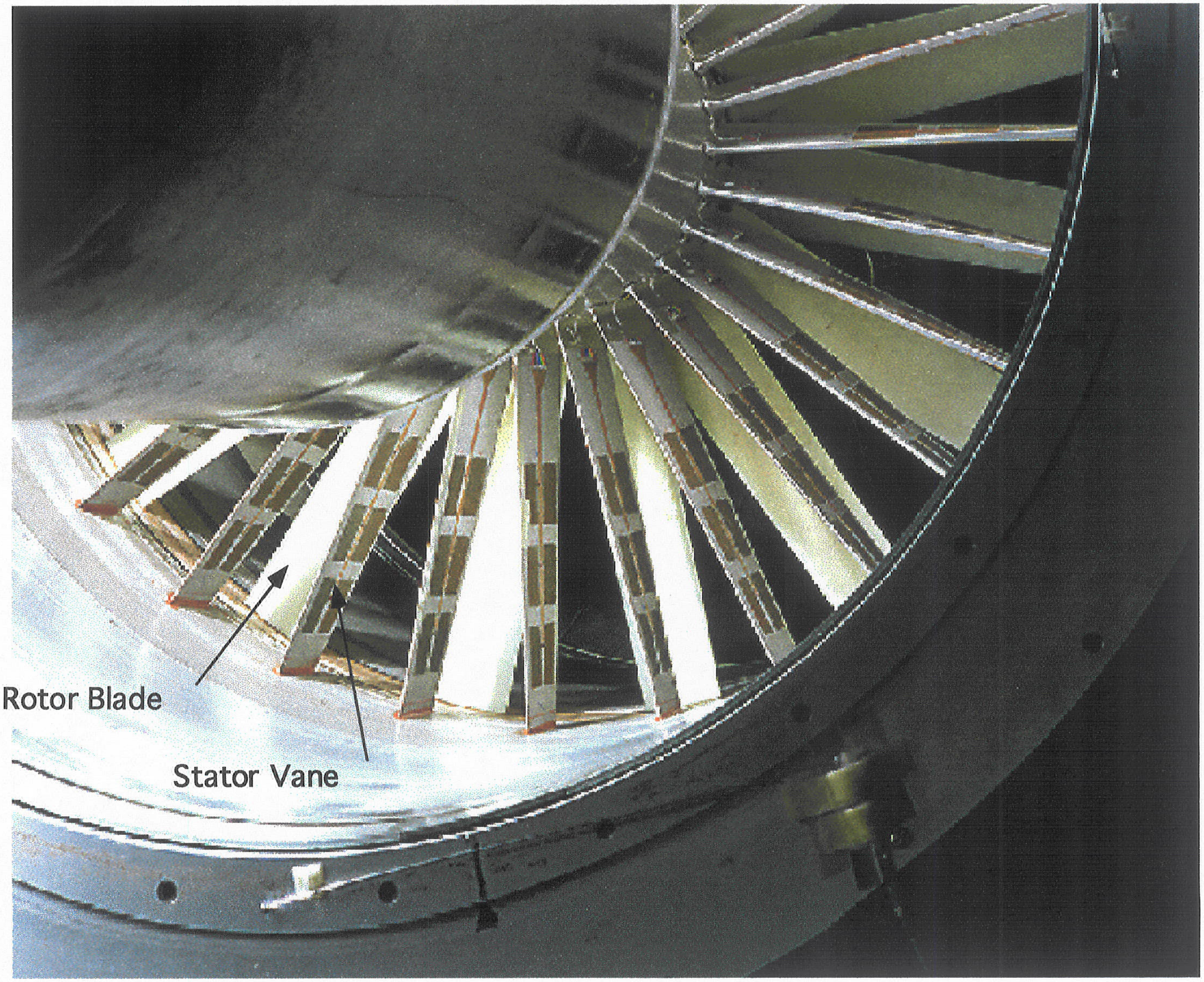
Fan Noise Reduction



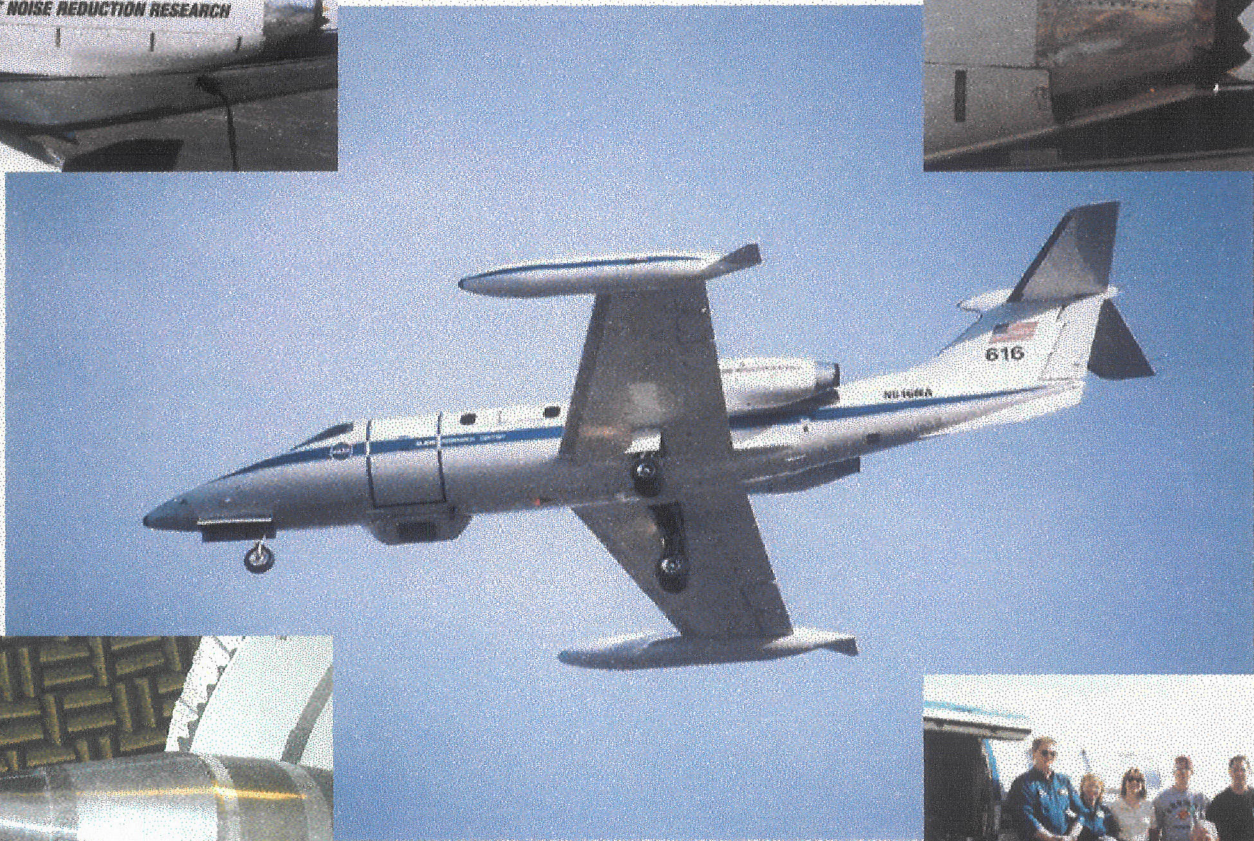
Virginia Polytechnic Institute Herschel-Quincke (HQ) Tubes
NASA Advanced Noise Control Fan (ANCF)

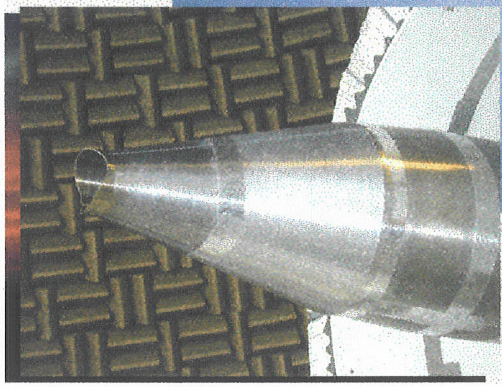
Fan Noise Reduction

NASA/BBN Active Noise Control Fan Test



Jet Noise Reduction – Flight Tests

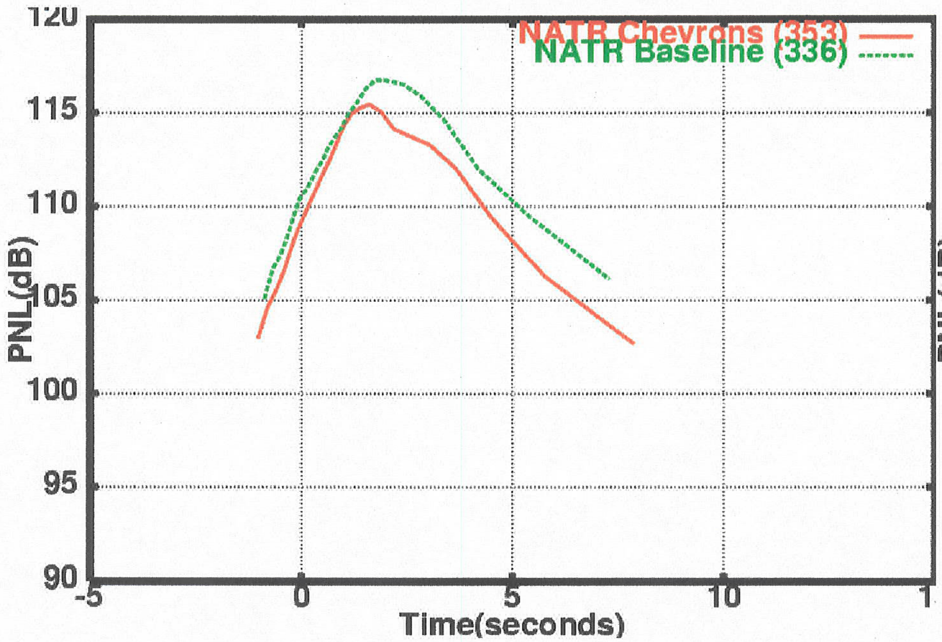




Model Scale Versus Flight Tests

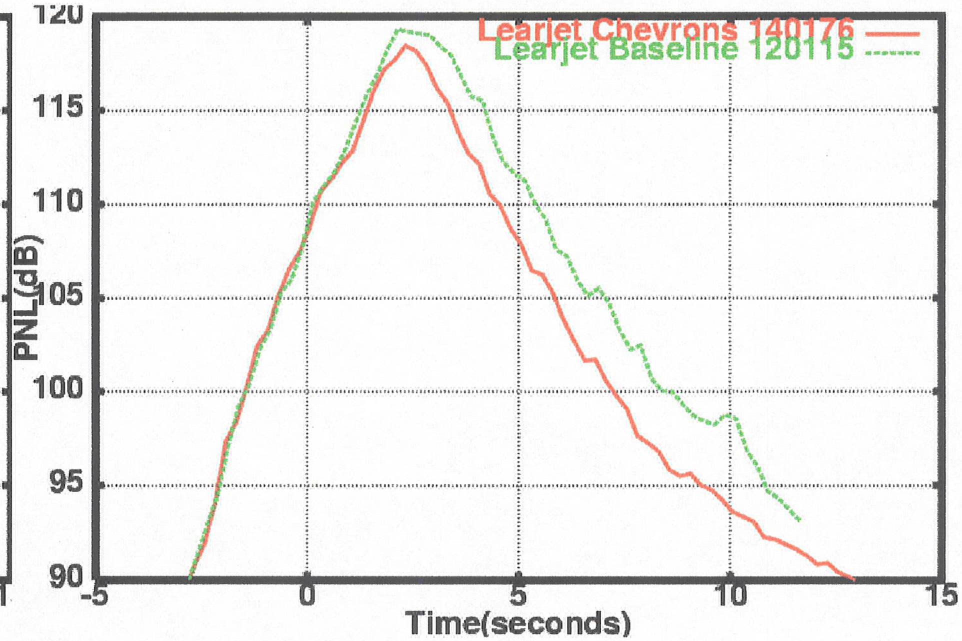
Chevron Benefit Comparison - Perceived Noise Level (PNL)

Model Scale Tests



vs.

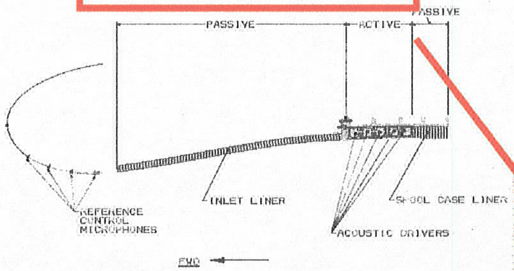
Learjet Flight Data



Brown & Bridges (*NASA TM 2003-212732)*

Pratt & Whitney PW4098 Engine Test

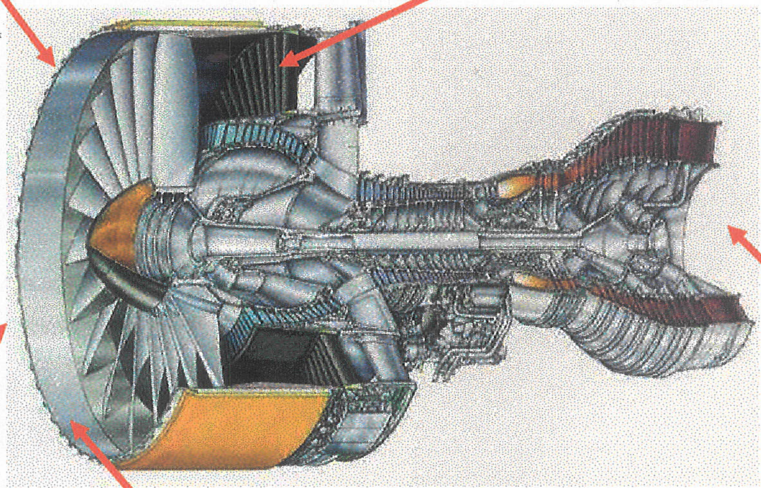
Active-Passive Liner



NORTHROP GRUMMAN

Scarf Inlet

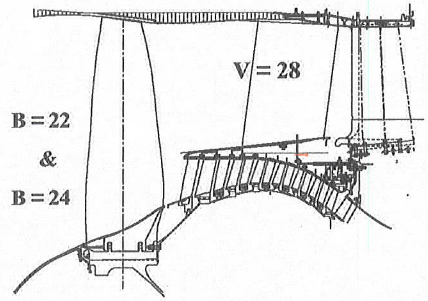
BOEING



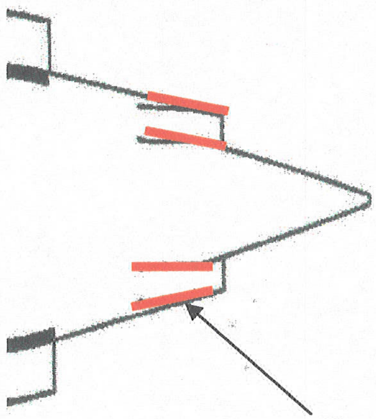
Pratt & Whitney
A United Technologies Company

Advanced PW Fan Case Treatment

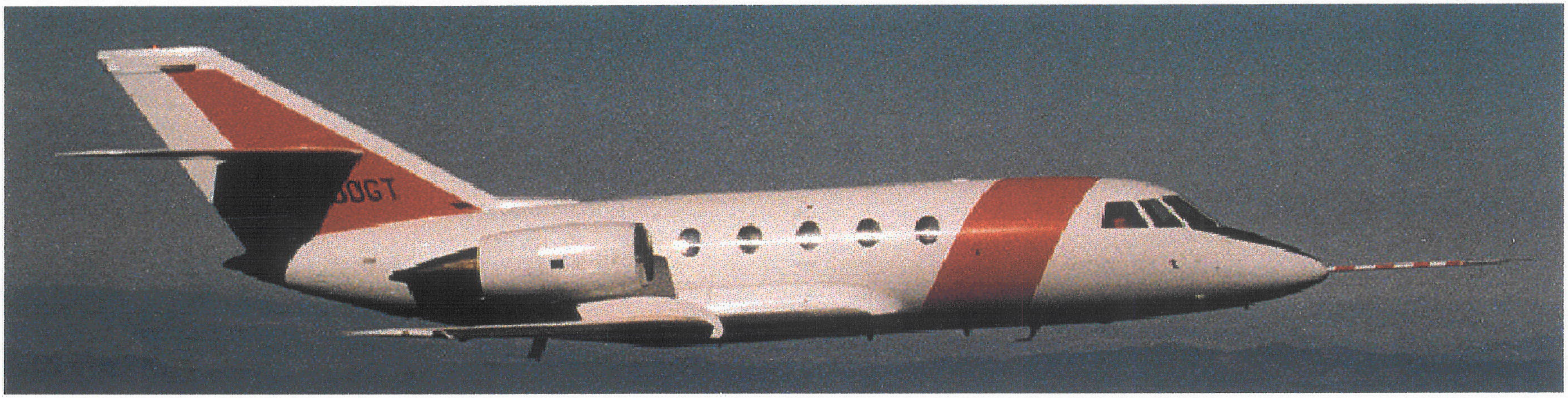
Fan Blade # Change and Low Number/Cuton FEGV

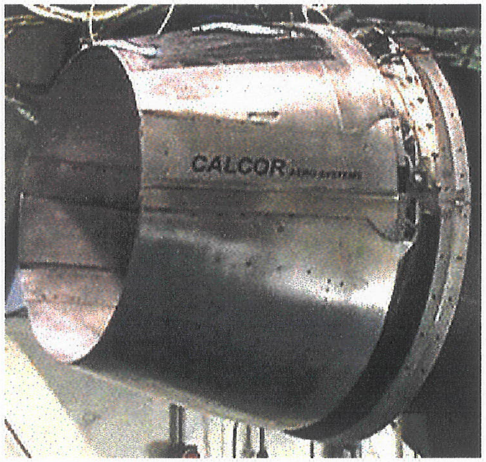


Treated Primary Nozzle

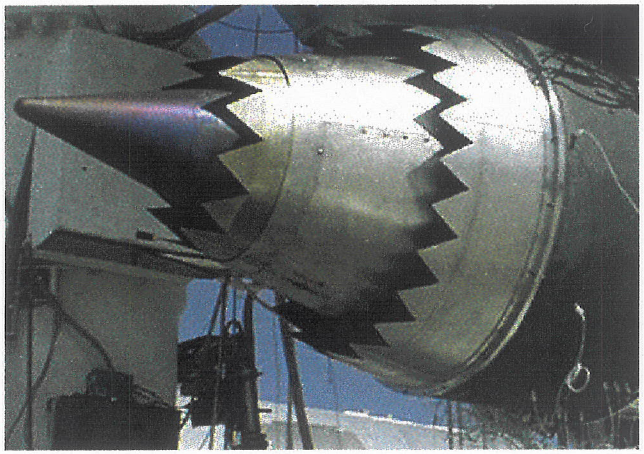


Honeywell Flight Demonstration of Noise Reduction Concepts

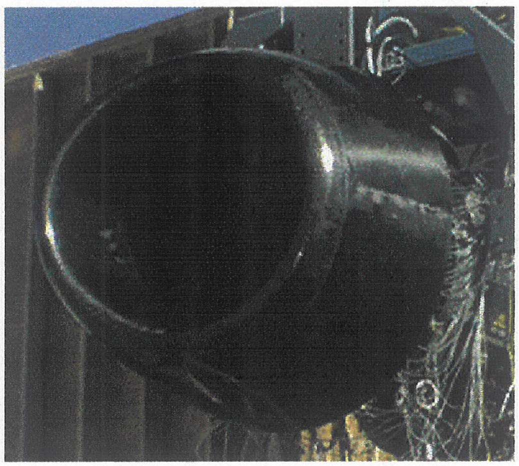




Variable Nozzle



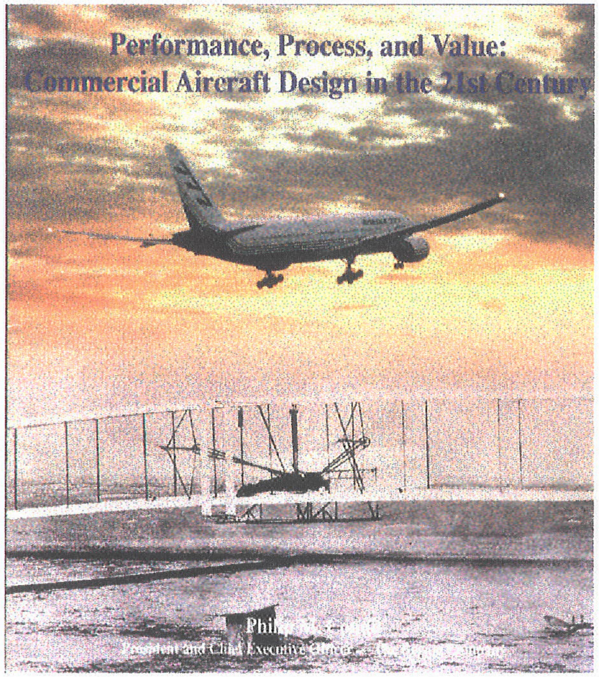
Chevron Nozzle



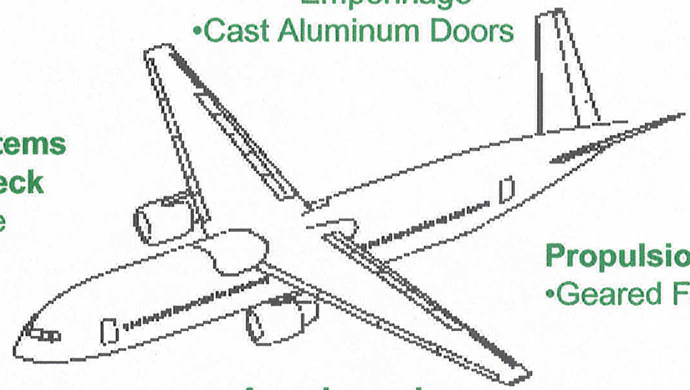
Scarf Inlet

1996 Wright Brothers Lectureship in Aeronautics

by Philip M. Condit, The Boeing Company, October 22, 1996



2016 Subsonic Airplane



"Ultra-high-bypass-ratio engines [to] reduce fuel consumption, engine maintenance, and community noise. It might be possible to reduce community noise by 10 dB, thus making airplane noise a non-issue at airports."

Dual-Fan Engine Concept On Blended Wing Body